SENSITIVITY ANALYSIS OF WAVE AUTOSPECTRAL ESTIMATES DUE TO TIME AND GEOGRAPHICAL VARIATION IN MALAYSIAN WATERS

By

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14534

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CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof. Ir. Dr. Mohd Shahir Liew)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

Sept 2014

CERTIFCATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AZMI HADZALIE BIN NORDIN

ABSTRACT

As an engineer, design aspects of a structure is definitely vital in construction of buildings as it determines what engineering considerations are being made in reference to standards to build a structure. In relation to that, autospectral estimates are considered as an integral when it comes to design consideration of offshore structures. This tool is considered as the fundamentals in the computation of values that are set out in design codes and standards. Autospectral estimates does not only help in computing values for design of structures but as well as operational criteria for transportation and logistics of vessels and barges. A current spectral model that is being adapted by Malaysia in reference to the PETRONAS Technical Standard (PTS) is that of the JONSWAP and Pierson-Moskowitz Spectrum where this spectrum model was derived in the past at a much aggressive region which are the North Atlantic Ocean and North Sea. Through this understanding a more conservative spectrum that is appropriate for Malaysian waters must be computed. This way the design value that are being adapted can be optimized for designing and operational purposes for offshore and marine activities. With relation to this research project, this report will be discussing and analyzing on how the derivation of spectral model will be conducted for the practice in Malaysian waters.

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CHAPTER 1: INTRODUCTION OF PROJECT

INTRODUCTORY:

In designing and analyzing offshore structures in the field of offshore engineering the hydrodynamics and dynamic responses on the offshore structure is to be fully understood as these forces makes up the engineering design. The load that makes up the forces acting on an offshore structure is environmental loads. The nature of an offshore structure being isolated in the ocean shows how important natural dynamic forces affect a structural behavior. The environmental loads that need to be studied comprise of 3 main forces, which are wind, wave and current. These 3 main forces are naturally occurring and therefore the depth of understanding these natural forces are complex as one may say that either of these forces affects the other, thus being dependent on the other, for example, the relation of wind speed and the behavior of waves. As mentioned, wind loadings are part of the environmental loads acting on an offshore structure, for this, the wind speed acting on an offshore region needs to be studied in designing. In contrast with on land buildings, waves and current will definitely be present as offshore structures are built in the ocean. In studying the behavior of waves, the wave height becomes the catch of the eye as it determines how high the wave generates and alarming it becomes as it not only affects the engineering design of an offshore structure but as well as the operational procedures and criteria in relation to offshore activities. As the foundation or support of an offshore structure is to be submerged or be in the ocean, ocean current takes over in the engineering design. A general understanding of ocean current can be said that the current speed varies with relation to specific depths and even to regional depth of the ocean. All these forces can be termed as Meteorology Oceanography (MetOcean) variables as it arises from the actions that occur in the ocean which are wind, waves and current.

In this engineering study on Malaysian Waters, the focus of this study is on the behavior of a specific environmental load which is Wave. As waves are natural causing, the understanding of its unpredictable nature can however be interpreted in a complex concept. In mathematical terms, waves can be presented in functions and be further interpreted through a Fourier series in terms of a combination function of sine and cosines. In Chakrabarti's publication, wave forms can be further generalized into periodical signals, where there are regular, irregular and random waves.

To further understand waves, it can be presented in energy spectrums. In general physics terms, waves are associated with the transfers of energy, therefore a comprehensive understanding on waves can be done through energy representation. With relation to the study on energy spectrums associated to waves, mathematical spectrum models are being developed to accurately produce a statistical property representing the energy of a wave. The energy spectrums that are developed and currently being put to practice, includes the Pierson-Moskowitz (PM) Spectrum, Bretschneider Spectrum, JONSWAP Spectrum and more. The designing of offshore structures in Malaysia uses a technical standard which is PETRONAS Technical Standard (PTS) 34.19.10.30, April 2012. The spectrum that is being adapted in the PTS in understanding waves is the PM and JONSWAP Spectrum. Through the understanding of the spectrum can the interpretation of waves be done, where important components such as Significant Wave Height and Associated Period can be determined. Therefore, the basis of representation of the referred spectrum must be correct before extracting the values. With reference to the practiced spectrum in the PTS, a general assumption can be made that the adapted spectrum is not relevant for this water region. This can be simply explained due to the fact that the spectrum was first computed in different water regions. For this, a specific Malaysian spectrum suitable for Malaysian regions must be used accordingly to extract important information.

PROBLEM STATEMENT:

The area of this research topic is part of the field of offshore engineering as a study on the waves is to be conducted. As waves are environmental loads acting on an offshore structure, the main purpose of this research topic is to make an understanding of depth in analyzing the components which affects the offshore structure. Therefore, this will lead to the alteration of offshore designing criteria's that is currently being practiced in Malaysian Waters. The statement that needs to be highlighted out is that the energy spectrum that is being practiced in the PTS is not optimized for local conditions. From this statement, problems related to offshore designing arises such as an overestimation of designing. A typical offshore platform for oil and gas activities last for an approximation of 25 years. Thus, the platform needs to be designed for 25 years and end there. However, Malaysian oil platforms are currently still stable even after 40 years of service. This clearly shows that Malaysian oil platforms are overly designed since the beginning and thus having difficulties in assessing the future asset and structural integrity of the platform. The basis of this over design platform is due to the practice of the energy spectrum that is being used with accordance to the PTS. With reference to the PTS, as an offshore engineer in designing the platform specific values such as Wave Height and Periods are already stated in the PTS for specific regions which by definition is incorrect. Thus, these values needs to be recomputed and not by referring to an energy spectrum that is based on other ocean or sea region but only to Malaysian waters.

PROJECT OBJECTIVE:

In accordance to the project title of the research, a very general objective for this research is to conduct a study on waves with relevance to Malaysian Waters. In achieving this, a more technical and scientific approach needs to conducted where the objectives are as follows:

- To perform a sensitivity analysis on wave spectral parameters
- To extract and process MetOcean raw data through the facilities provided
- To derive energy wave spectral plot in relation to temporal (time) & spatial (location)

RELEVANCY & IMPACT OF RESEARCH PROJECT:

With reference to the above Problem Statement section, PETRONAS carigali oil platforms are currently being overdesigned as the platforms from 40 years are still stable and well intact. Therefore, a general assumption can be made whereby if the platforms are designed accordingly much can be saved in terms of dollars and cents. From the outcome, the energy spectrum produced will optimize the values and numbers that are to be used in engineering designs. The PETRONAS Technical Standard that is being used in designing offshore structures will be reanalyzed and a much relevant figure will be put to practice. The values that are to be analyzed include the operational criteria and storm events that are vital for offshore operation and activities. With relation to the results produce, not only does the contribution of this research is in the aspect of designing but as well as operational selection of offshore activities. This can be explained by the type of ships that are to be selected and determined for operational and transportation purposes to the offshore structure. Selecting the right vessel for the operational criteria is also a key component as it determines the transportation of cargo and human resources. In terms of the research conduct of the project, the feasibility of the project is within the students' grasp, where all the feasibility elements discussed later is provided. Therefore, the main significant of this research project can be summarized to produce an optimized engineering design which will help in saving operational and designing expenses related to offshore structures.

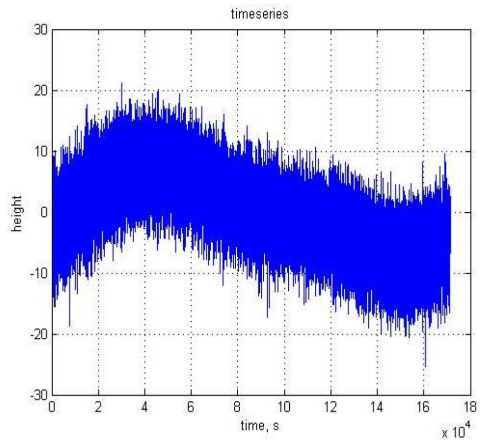
FEASIBILITY & SCOPE OF STUDY:

In assessing the feasibility of this research project, it can be divided into 4 main parts as it is the basis of aspects of the research's components. The first component of this research project is the MetOcean Data, the raw data which describes the activity of the waves. This is the main key component in conducting a study on waves and this is provided and obtained through PETRONAS. Facilities in extracting and processing the raw MetOcean Data for this research project is conducted through computer software such as MATLAB and SPSS for the statistical and mathematical approach which is time consuming.

Industrial reference in conjunction to this research project includes the PTS and API standards which is provided and available for referencing. References for this research project on MetOcean variables and technical background is much available as studies on MetOcean are not new. The scope that will be covered throughout this research project is as specified in the objective of the research project and the conduct of all the objectives is based on the feasibility aspects that is present and provided. As the processing and analysis of raw MetOcean data is conducted through the available software and the outcome is the spectral plot which represents energy in the frequency domain which is further understood through comprehensive theoretical background on the energy spectrums available. Based on the raw data that are available for this research, the Malaysian Water regions that are available which are PMO, SKO and SBO which comprises the spatial parameter of the wave spectral and the data available is from 2011 to 2013 therefore an analysis on seasonality can be conducted which covers for the temporal parameter. Therefore this research project is definitely feasible and scope of study in processing and interpreting the results is achievable within the conduct of Final Year Project I (FYP I) and Final Year Project II (FYP II).

PROJECT LIMITATION & DRAWBACK

In pursuing the end of the research project, recent observations of current available wave data proves to be misleading as local wave amplitudes are not representative of local Malaysian sea waves. As reported in S. Amurol et al’s OTC paper (2014), a peak amplitude wave height in a storm event will have an amplitude of 4 meters at the region of Sabah and Sarawak, and a daily wave amplitude of 2 meters. In relation to current wave data, wave plots show daily wave height as high as 10 meters in amplitude which is not relevant and representative to current publish work of the region of SKO and SBO. This can be clearly seen in the following plots:



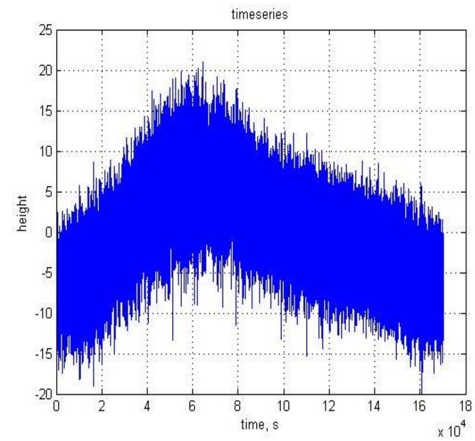


Figure 1.0: Sample of Wave Data plots for SKO & SBO region

As the wave data is not representative to Malaysian waters with reference to onsite observation and current publications, the following results in this report is not representative for the regions to be studied, SKO and SBO. However, this research project is continued as an understanding on the methodology and approach in solving the problems faced in producing the wave energy spectrum.

CHAPTER 2: LITERATURE REVIEW

ENVIRONMENTAL LOADS:

As explained in brief, the loads that act on an offshore structure are environmental loads. To interpret the environmental loads acting on the structure an understanding on the environmental conditions that are present in that location must first be determined. According to D.N. VERITAS (2010), Environmental conditions of a location cover all the natural phenomena that are occurring at that location which in some define as a contribution to structural damage, operation disturbance and navigation failures. The most important phenomena and is most concerned in marine & offshore structures in Malaysian waters are wind, wave and current. However, there are more environmental conditions that may be put to consideration which includes, ice, temperature and even earthquakes but with relation to the standards that are covered by the PTS in designing offshore structures, are wave, current and wind. In relation to these loads, a general picture on the acting forces can be described in laymen terms that wind forces acts on a topside of the structure, wave's acts at the surface water level and current acts throughout the water depth. In understanding the concept of wind, it can be divided into 2 categories of wind which are mean wind speed and wind gust speed. Mean wind speed is defined as the wind force acting on a structure throughout a period of time where the forces affects the structural frame and system. Wind gust can be termed as a brief of sudden burst of increase in wind speed which in general affects the structural components on the structure. Both these conditions are considered in the PTS where either a 10 sec or a 1 min mean wind speed is adapted and a 3 sec wind gust is used and the common practice of wind speed is at a reading of 10m above sea level. In engineering practice, the primary concern of wind is the wind drag force acting on the structure where a drag force formula is used which are associated to constants such as shape coefficients are included as prescribed in the API Recommended Practice (2000). Wind and waves are associated with each other as the generation of waves is from wind where it applies the basic energy principle of energy transfer. According to A. McMillan et.al (2011), when a wind blows through the water surface in a fetch, it will gradually develop the wave height and period which is dependent on the strength and duration of wind acting on the water. The generation of wave within a fetch region in the ocean is termed as sea waves, whereas swell waves are termed as the normal waves after the projection of the sea waves from the fetch. D.N. Veritas explains that current is considered in any offshore design as it can affect the structure through the drift of motions of the platform, drag and lift forces and also create vortex induced vibrations on the slender structural elements. The current velocity is the main concern and it varies through water depth and also due to time but in most applications, the current velocity is considered as a steady flow and interpreted in a function of depth as in the PTS, 3 main depth points are stated, at the surface water, at 0.5D and at 0.01D where the velocity is interpreted in a linear relation. These 3 environmental loads make up the forces acting on an offshore structure and needs understanding for designing.

WAVES:

W.H. Michel (1968) claims that waves in the sea are never regular as it does not depict itself in a series of uniform waves of constant height and length thus having the property of irregular and random at the same time. Therefore, in understanding the waves in the sea, a mathematical and statistical approach must be done in comprehending the waves. In relation to this, many water wave theories are being produced in the development of studies in waves where mainly the theories are dependent on specific environmental parameters such as water depth, wave height and period. In Chakrabarti's publication (1968), several regular wave theories have been developed into describing the water kinematics such as the basic Airy wave theory, Stokes high order theories, Cnoidal wave theory and Stream Function wave theory where these theories are linear and non-linear. N. Haritos (2007) explains that in modelling the irregular ocean sea state character, it is often depicted as the superposition of a number of Airy wavelets of varying amplitude, wavelength and direction which all together models out the irregular character of waves. The wave characteristics that needs attention and are normally focused are Significant Wave Height (H_s), Zero Crossing Period (T_z), Peak Period (T_p), Maximum Wave Height (H_{max}) and Associated Period (T_{ass}) as mentioned in the PTS for designing offshore structures, a statistical distribution in understanding the wave height can be seen in Figure

1.2 from C.L Bretschneider's publication (1964). A much comprehensive understanding on waves can also be done through the understanding of energy spectrum which will be discussed later. Computation of wave forces is one of the primary tasks in offshore designing, where the computation of wave can be done in 3 different methods, Morison equation, Froude-Krylov Theory or Diffraction theory, where a general understanding can be said that the Morison equation is used for small structures, the Diffraction theory is used for floating or very large structures and the Froude-Krylov theory is for structures that are in between this category. The adapted method in offshore designing with reference to the API is the Morison equation, where it is the combination of drag and inertial force of the wave where it consists of the drag coefficient (C_d) and the inertia coefficient (C_m). For this research project, as described in the objective, the energy spectrum produced by the waves will be the main focus and scope of this project.

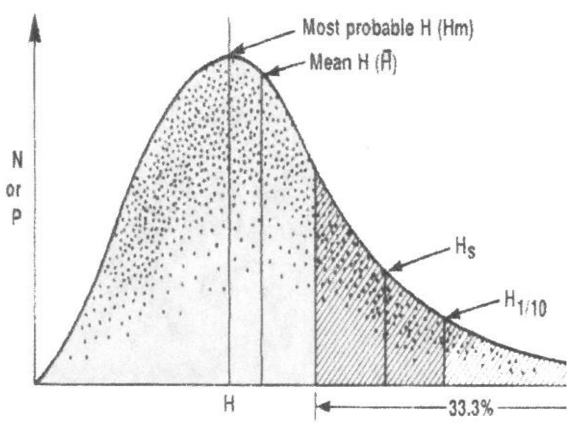


FIGURE 1.2: Statistical Distribution of wave height (C.L. Bretschneider, 1964).

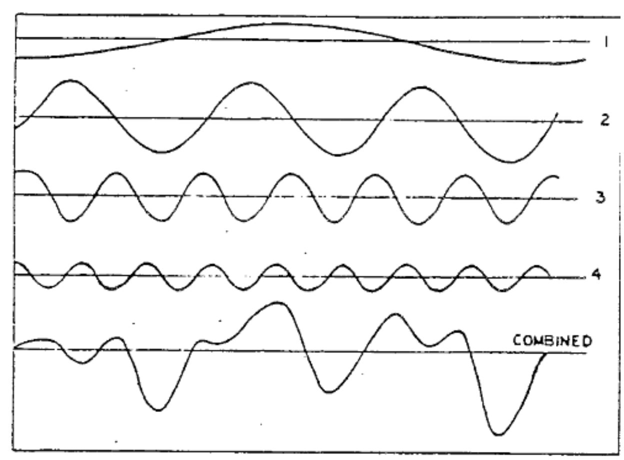


FIGURE 1.3: Combination of regular waves (W.H. Micheal, 1968).

ENERGY SPECTRUM MODEL:

In W.H. Michel's publication on sea spectra, irregular sea waves is a result of the superposition of regular waves of different lengths and height which can be described in Figure 1.3. From this representation it can be clearly seen that the formation of irregular waves is due to regular waves and through this basic concept the wave shape produced by irregular waves is a resultant of all the regular shape waves. From this undistinctive wave pattern, irregular waves are characterized not through the wave shapes but through the energy spectrum it produces. In laymen terms, the resultant wave energy from the irregular waves can be defined as the summation of all the energies produced by the small and regular waves which makes up the energy spectrum. Chakrabarti interprets the energy spectrum as a mathematical spectrum model where the model is based on parameters such as wave height or wave period etc. The most common and very well-known spectrum is the Pierson-Moskowitz (PM) (1964) model whereby it is a single based parameter which is based on significant wave height or wind speed. The energy spectrums that are in practice includes the JONSWAP (1973) spectrum, ISSC (1964) spectrum and Bretschneider (1969) spectrum. All the spectrums having a function in terms of wave frequency (ω) whereby, the empirical formula of each spectrum varies due to modification and understanding with relation to the parameters as some having a 2 parameter spectrum and even a 5 parameter spectrum. The basis of the spectrums are also due to location and the development of the sea where the computation of the spectrum are based on MetOcean data obtained from the North Sea or the North Atlantic Ocean where the analysis of the waves can be either a fully developed sea wave or partially developed. The variation on the type of spectrums can be depicted in Figure 1.4. With relation to PTS, the adapted spectrum in Malaysian water basin is the JONSWAP and PM spectrum. However, the spectrum adapted is not optimized to local South China Sea conditions as the basis of the MetOcean data in computing the energy spectrum is much higher in the North Sea and North Atlantic Ocean, where a generalization can be made that Malaysian waters are not as rough as the others. According to W.J. Pierson & L. Moskowitz (1963) in the works of Kitaigorodskii, the first spectrum developed was based on a function of four variables which is frequency, gravity, friction velocity and fetch. As PM spectrum is a fully developed sea, the dependence of fetch vanishes and a final empirical formula of the PM spectrum can be as follows:

$$S(\omega) = \alpha g^2 \omega^{-5} \exp\left[-1.25\left(\frac{\omega}{\omega_o}\right)^{-4}\right]$$

The JONSWAP model being a partially developed sea can be formulated as follows:

$$S(\omega) = \alpha g^2 \omega^{-5} \exp\left[-1.25\left(\frac{\omega}{\omega_o}\right)^{-4}\right] \gamma^{\exp\left[-\frac{(\omega-\omega_o)^2}{2\tau^2\omega_o^2}\right]}$$

In W.H. Michel, partially developed seas are the first wave generated that are those of short length and later as wind continues blowing, long and longer waves are generated and eventually the system becomes stable where no effect is produced, no matter how much longer the wind blows over any area, until this final condition it is known as a fully generated sea. From the depicted graph of the PM and JONSWAP spectrum, an assumption can be made that a much lower energy spectrum is to be predicted in relation to Malaysian waters as the MetOcean data values obtained will be lesser in value and thus being able to optimize the values required in designing offshore structures in relation to the practiced standard and guideline in Malaysia with relation to temporal and spatial parameters.

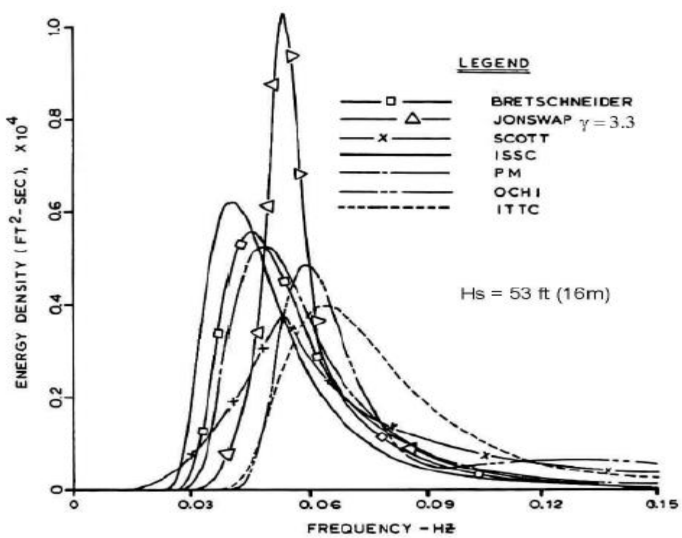


FIGURE 1.4: Energy Distribution of different spectral models (Chakrabarti, 1986)

CHAPTER 3: METHODOLOGY

NATURE OF INPUT DATA:

To process or analyze the data, an understanding on the nature of the given data must be done to effectively obtain results which are valuable. For this research purpose, an understanding on the Met Ocean data must be comprehended before processing it further. In understanding the available Met Ocean data obtained through PETRONAS, the data which is to our concern is Raw Wave Data which is collected through sample recording at a specific Malaysian water basin region using a recording equipment such as a buoy. In relation to the recorded wave data, the sampling wave record is at every half second and continuously throughout the day of recording. The data population is currently limited as the representation of the wave data is only to the region of SBO and SKO. The relation of these water basins will be further analyzed in the later part of the research project.

TIME SERIES:

As mentioned, the sample of the data is recorded in time, seconds, this interprets that the raw data is in the time domain. In relation to the time domain a specific term of analysis can be determined through the nature of the raw data which is Time Series Analysis. P.J. Brockwell et al (1986), explains that a time series analysis are problems related to observations that are collected regularly in time intervals in which correlation exists among the successive observations. Time series on its own is a vast field of descriptive statistics in which the sets of data are natural occurring and can be used in many fields of application such as economics, finance, environmental, medicine and many more. The reason of the usage of a time series analysis is due to the stochastic nature of the process involved, for this research, as explained; waves are natural occurring and stochastic in nature which fits the criteria of a time series. In comprehending the method used in the time series analysis, P.J Brockwell et all explains it in layman term as a classical decomposition of a matter in relation to time. This is then comprising of four main factors, which are trend, seasonal effects, cycles and residuals. A time series is a combination of all these four elements and therefore understanding each of this element makes us closer in understanding and comprehending the time series of a set of data. From here much can be used from the findings, such as future prediction and outcomes, which is widely used in stock exchange for such benefits. A further depth of understanding of the 4 factors can be explained as such:

Trend: Long term movement of mean/average

Seasonal effects: Cyclic fluctuation related to period/actual calendar

Cycles: Other cyclic fluctuation (business cycles etc)

Residual: Random/Systematic fluctuations

However, before moving to further statistical approach a plot on the time series must be conducted in order to observe and visualize the existing time series on determining the representation of the existing raw data. This is to casually observe the variation of the raw input of time series data. A time series plot can be represented in Figure 3.1 and 3.2, whereby it is the representation of the time series plot of available raw wave data.

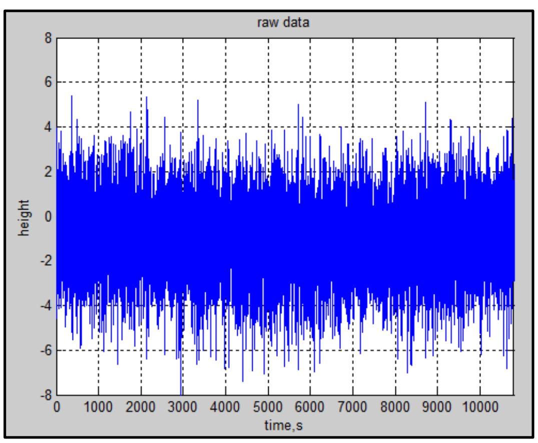


Figure 3.1: 3-hour Time Series Plot

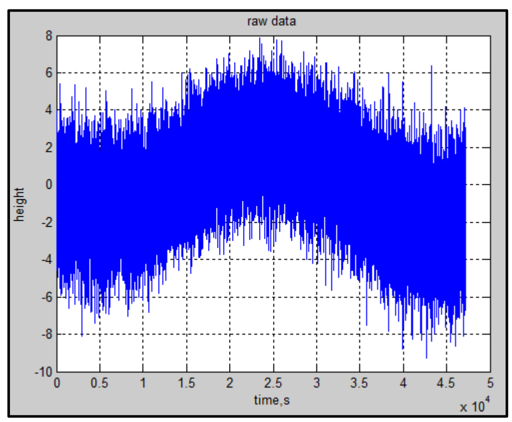


Figure 3.2: 1-day Time Series Plot

As can be seen such a random/stochastic nature can be seen in the raw wave data obtained by simply plotting the amplitude of height (m) against time (s). However, by solely depending on this time series plot nothing can be deduced because the important parameters are not identifiable. Therefore, an extended approach in identifying the important parameters are conducted to make this visible and clearly identifiable. This approach is by simply observing the input data in a different domain which is the Frequency Domain.

SPECTRAL ANALYSIS – FREQUENCY DOMAIN ANALYSIS

In Don Percival (n.d) works, Spectral Analysis is a widely used method in data analysis in many fields such as geophysics and astronomy whereby a simplification is obtained to a set of time series by converting the set of series into a different domain which is the frequency domain. A much comprehensive understanding in Spectral Analysis is that, it decomposes a stationary time series to a combination of sine and cosine functions whereby a coefficient of each parameter is introduced. This method of adaptation can be specifically termed as a Fourier analysis whereby Fourier Transform is applied to convert the time series into the frequency domain. According to G. S. McDonald (2004), in understanding Fourier series, it is a combination of signals in periods of sine and cosines which is defined in coefficients, this can be represented in the following equation:

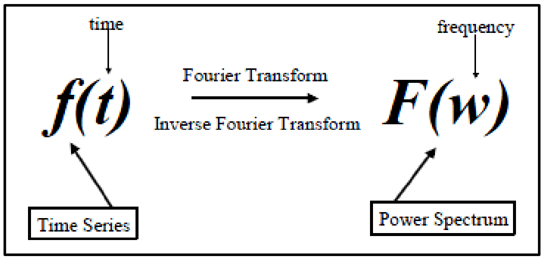
$$x(t) = a_0 + 2\sum_{n=1}^{\infty}\left(a_n \cos \omega_n t + b_n \sin\omega_n t\right)$$

$$a_0 = \frac{1}{T}\int_0^T x(t)dt \qquad a_n = \frac{1}{T}\int_0^T x(t)\cos \omega_n t\, dt \qquad b_n = \frac{1}{T}\int_0^T x(t)\sin \omega_n t\, dt$$

In his publication as well to understand further on time series, it must be first brought to the frequency domain, this is done using the Fast Fourier Transform (FFT) where a function of frequency is produced from a function of time. A basic mathematical representation of this can be shown as follows:

$$F(\omega) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} f(t)e^{-i\omega t}dt$$

A basis on the Fourier Transform can be represented in the following Figure 3.3 and 3.4.



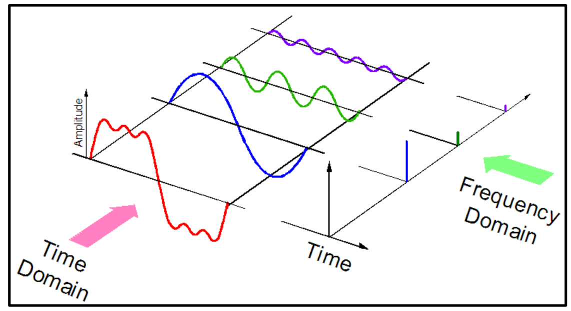


Figure 3.3: Fourier Transform Figure 3.4: Conversion to Frequency Domain

A clear purpose on the conversion to the frequency domain can be observed from Figure 3.4 whereby a set of time series is actually a combination of many series in different frequency ranges and therefore studying a series in the time domain makes it difficult or impossible to determine and identify important parameters. Through this a power spectrum is produced which is known as a spectral plot and for this research, a spectral plot on wave is produced. However, the use of FFT in converting the time series into frequency has its condition whereby the set of data must be stationary as mentioned before.

STATIONARITY:

As explained in previous section that the nature of our input wave data is random and stochastic in nature, however the relation of a point to the successive is present due to the nature of a time series. This relation can be identified and determined through the testing of stationarity. This method of determining the stationary of a set of series is important as mentioned before that in the process of FFT, the series must be in stationary form. Therefore, the testing of stationarity must be done and through this findings can then the series be modified to be stationary for further FFT analysis. In G.P. Nason's (2013) paper, a more definite explanation on stationary process is that it is a set of series in which the statistical properties does not change with relation to time. There are many statistical testing in determining the stationary of a series, however the method of adaptation in this research is the Autocorrelation Method. In G.P. Nason's paper states a basic formulation on producing a autocorrelation function which is as follows:

$$R(s,t) = \frac{E[(X_t - \mu)(X_s - \mu)]}{\sigma_t \sigma_s}$$

Through the ACF method, a generalization on the stationary and non-stationary can be observed through the graph produced whereby a plot of autocorrelation values against number of lags is plotted and behavior of the plot determines the stationary of the set of series. In G.P. Nason's publish, states that the autocorrelation values that are returned through the formula ranges from a value of 0 to 1 or -1. In identifying the stationary, a plot against the number of lags is done. As the number of lag increases and the autocorrelation values slowly reaches zero, this means that the set of data is non stationary. However, if the autocorrelation values dies of fast as the number of lags increase this means that the set of data is stationary. A sample of this plot can be observed in Figure 3.05.

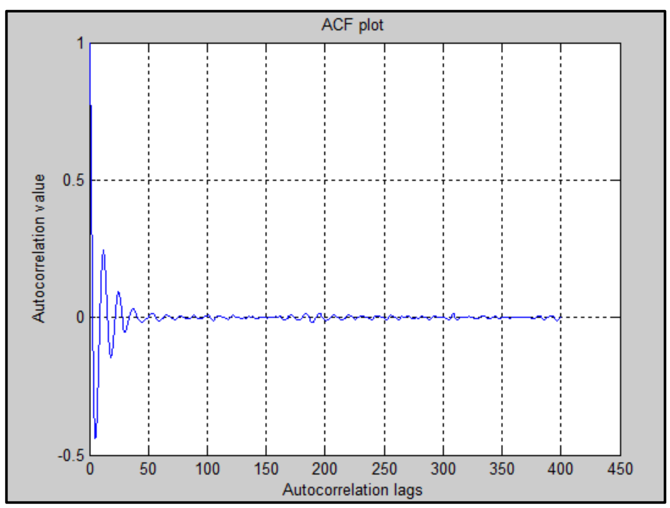


Figure 3.5: Autocorrelation Plot

From here, the stationarity of the series is obtained and if the series is non stationary other methods are introduced to make the series stationary such as Differencing. The reason to this non stationarity is due to high interferences of the raw data such as white noise.

Through this step by step methodology can then a representable spectral plot be produced and be represented as a spectral plot for the water basins in Malaysia. However, by blindly following the step by step procedure without understanding the fundamentals and reason behind it will lead to a not efficient approach, as much encounters in error will be presented along the way. After a spectral plot is achieved, the derivation of wave height of the region is done through simple computation of formula as to finding the equivalent value of the area under the spectral plot. This value is then related to the wave height through a basic formula which is explained in Chakrabati's publication:

$$H_s = 4\sqrt{m_0}$$

$$H_{rms} = 2\sqrt{2m_0}$$

Whereby, H_s is the significant wave height, H_{rms} is the Root-Mean-Square wave height and m_0 is the area under the spectral plot.

PROJECT KEY MILESTONE

In relation to the progression of the project, the following will represent the Key Milestone of this Final Year Project (FYP) covering 28 academic weeks. Whereby the current stage and progress of FYP is stated.

Key Milestone	Proposed Week
Extended Proposal (achieved)	Week 6
Proposal Defense (achieved)	Week 10
Interim Draft Report (achieved)	Week 13
Interim Report (achieved)	Week 14
Progress Report (achieved)	Week 21
Dissertation & Technical Report (current)	Week 25
Viva Presentation	Week 26

Table 3.6: Project Key Milestone

PROJECT TIMELINE – GANTT CHART

The following is a representation of the project time line throughout the Final Year Project, where the Key Milestones are highlighted out in the Gantt chart.

			Timeline (week)																											
No	Tasks:	Duration	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	Project Activities:																													
1	Introduction & Exposure to Research Project	2 weeks																												
2	Inception Activities & Reviews on reference	5 weeks																												
3	Data QC/QA - database	1 week																												
4	Decoding of raw MetOcean Data	2 weeks						**Extended Proposal**				**Proposal Defense**			**Interim Draft Report**	**Interim Report**							**Progress Report**				**Dissertation & Technical Report**	Viva		
5	Update & Review on collected Results	continuous																												
6	Processing of MetOcean Data	continuous																												
7	Compilation of Results	4 weeks																												
8	Analyzing & Discussion on Findings	3 weeks																												
9	Concluding & Documentation of Findings	2 week																												

Table 3.7: Project Gantt chart

CHAPTER 4: RESULTS & DISCUSSION

In relation to the conducted research project, much progress has been made and in arriving to the findings of the spectral plot of Malaysian water basins. As mentioned earlier, the current existing raw wave data only covers for the region of SKO and SBO, in which the specific data region is at Baronia and Erb West respectively. A complete study can be done with the presence of a representative data at any location at the PMO region. However, at the current stage of findings, it can be seen that not much variation can be seen with relation to the difference in region, whereby current results show that SKO and SBO are producing similar range of frequencies, this however needs to be further checked and interpret. In a more descriptive explanation, in achieving the spectral plots for the 2 regions, the raw data needs to be stationary as explained in previous chapters, therefore the data needs to be differenced to the first order where autocorrelation plots are computed and spectral plots are developed. The following represents a spectral plot for a data worth of 24 hours within a month at the location of Baronia, SKO through windowing procedures of differencing and autocorrelation.

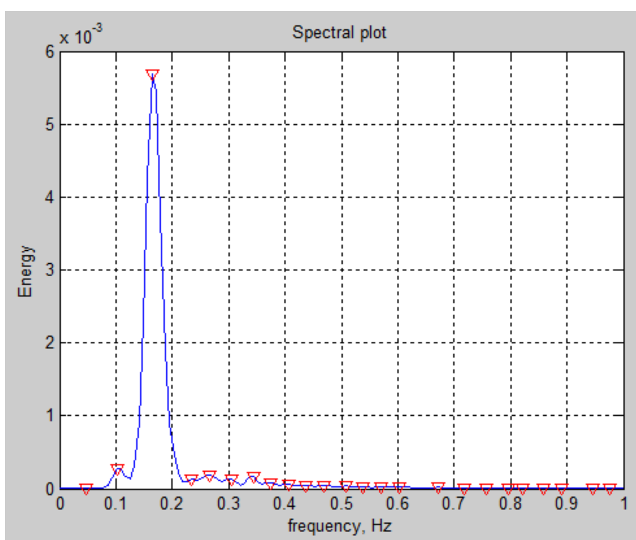


Figure 4.1: Spectral Plot of a 24 hour data in SKO region

However, based on Chakrabarti, the significant wave height, H_s can be derived from the energy content in the spectral plot, through a relation of area under the wave energy density, m_0. The derivation of m_0, was studied and in computing the correct H_s, the spectral plot produced must not undergo differencing and autocorrelation procedures, whereby the spectral plot is produced directly from the raw wave data measured. In achieving this, the elimination of moving average and trend must be done, whereby the average center of the nature of data must be at zero, therefore, it was found out that the length of data that is needed to eliminate all these factors is by using wave data worth of 500 seconds. Through analyzing 1000 points of data can the average mean be at the zero line. The relation of average mean and amount of data can be further explained as follows:

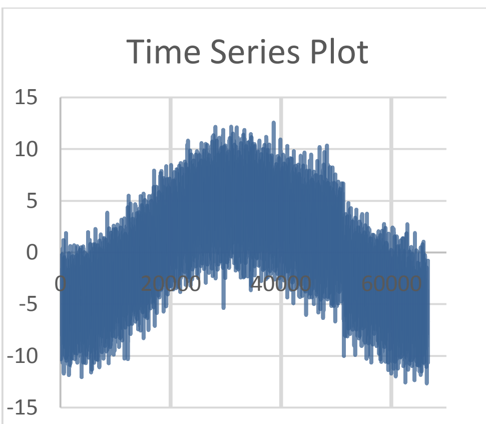


Figure 4.2: 24 hour data

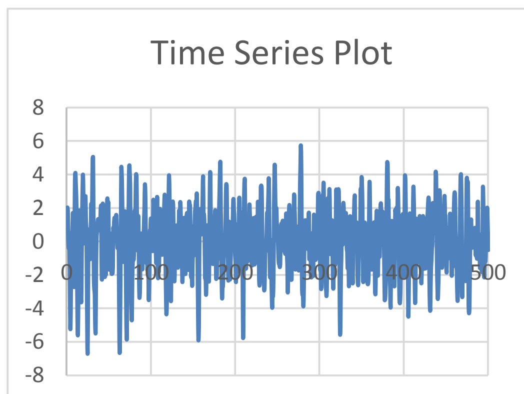


Figure 4.3: 500 second data

In optimizing the amount of data, the spectral plots are made and the computation of m_0 be done which leads to the findings of H_s. As other spectral plots for each day is computed for every month and data provided for each location, the enveloped spectrum of all of them is plotted in observing and producing a much comprehensive representation on the spectral behavior of the Malaysian waves. The spectral plots for each day of the respective month can be observed as follows:

Location: Baronia (SKO)

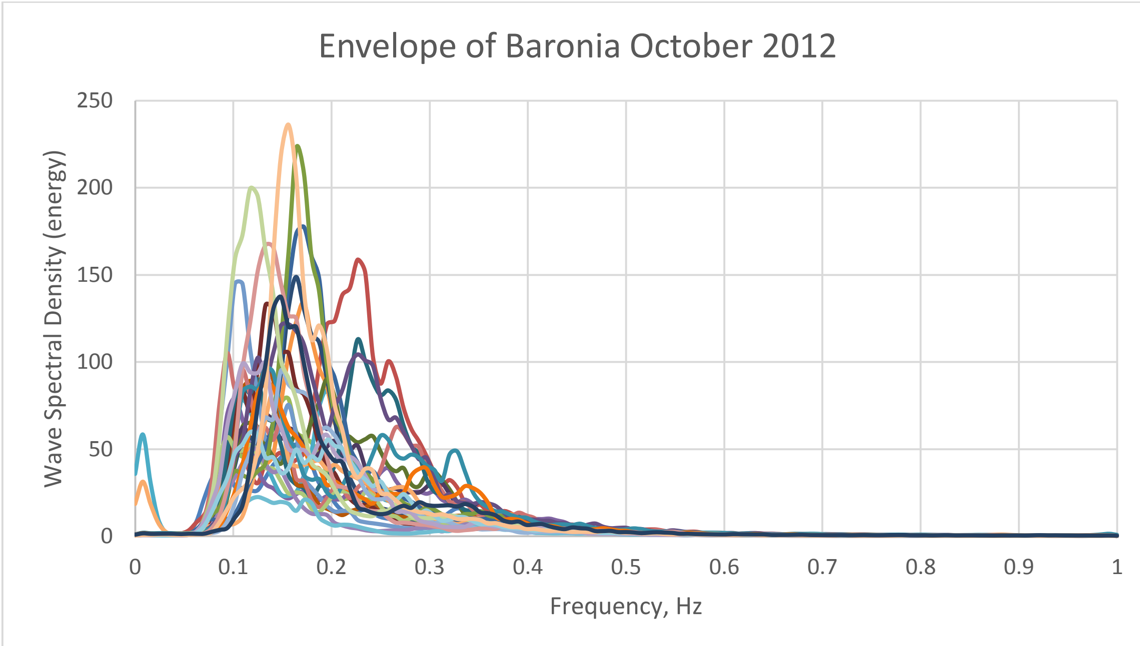


Figure 4.3.0: Wave Envelope Spectrum of Baronia October 2012

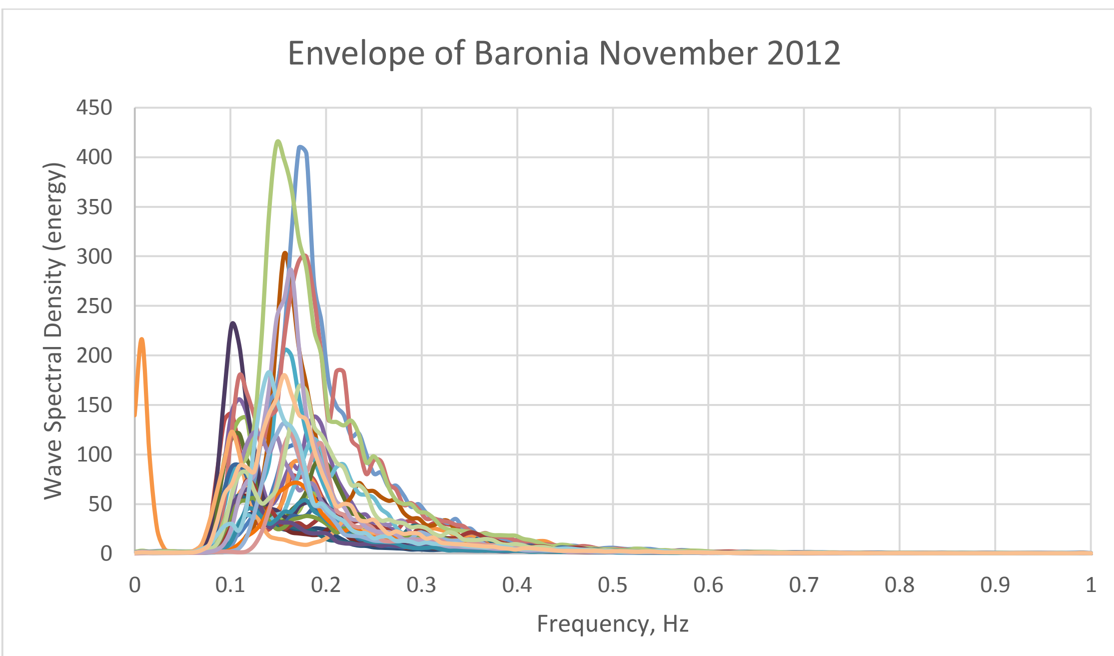


Figure 4.3.1: Wave Envelope Spectrum of Baronia November 2012

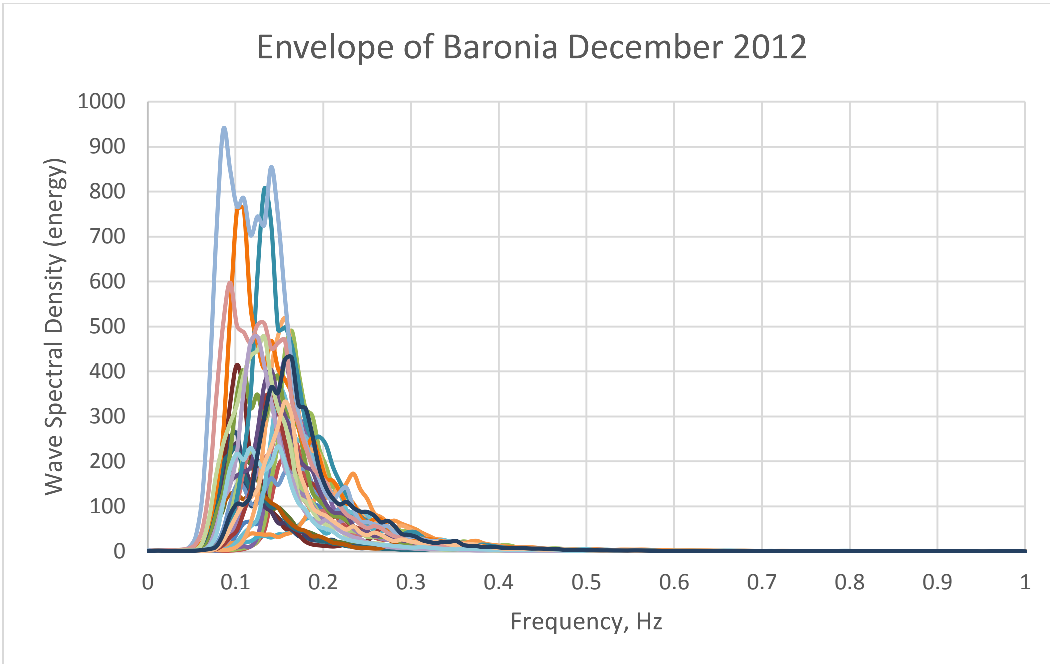


Figure 4.3.2: Wave Envelope Spectrum of Baronia December 2012

Location: Erb West (SBO)

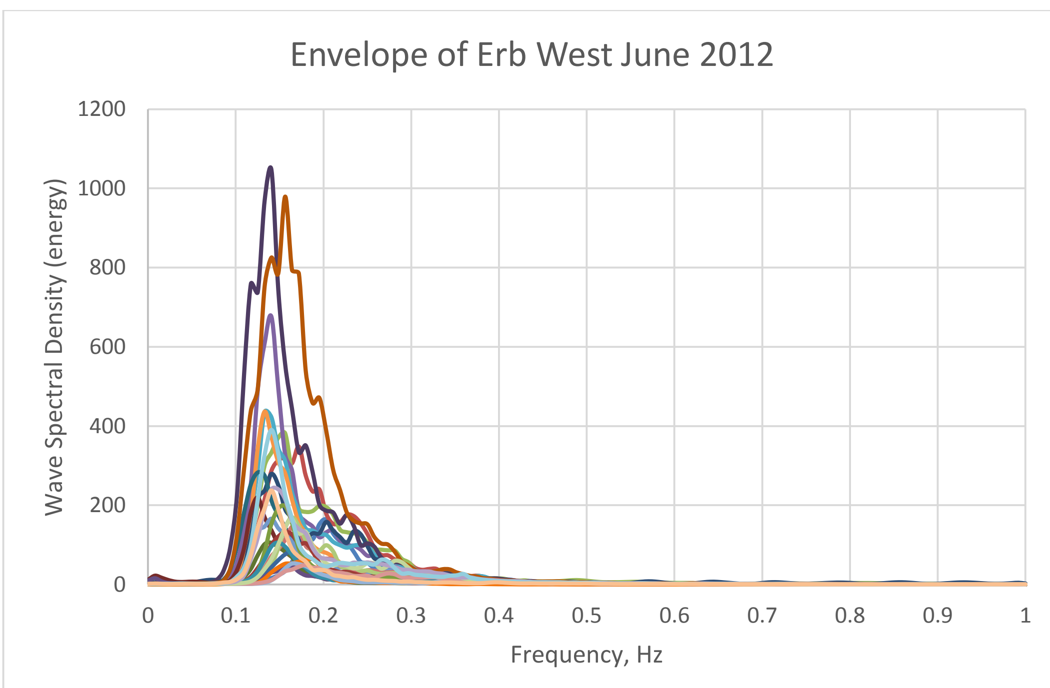


Figure 4.3.3: Wave Envelope Spectrum of Erb West June 2012

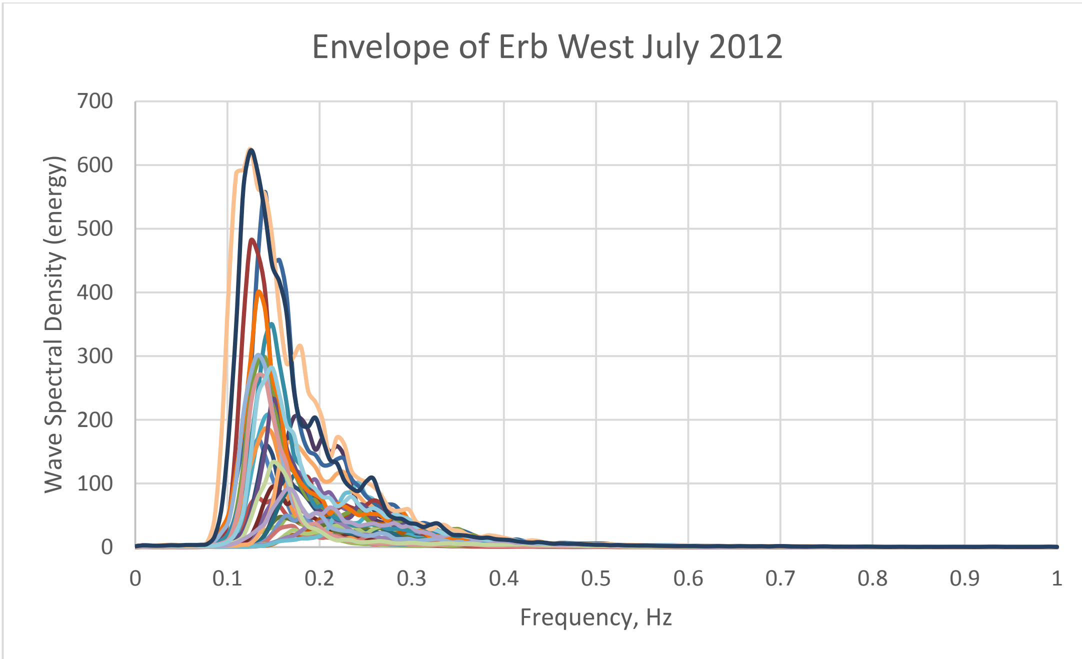


Figure 4.3.4: Wave Envelope Spectrum of Erb West July 2012

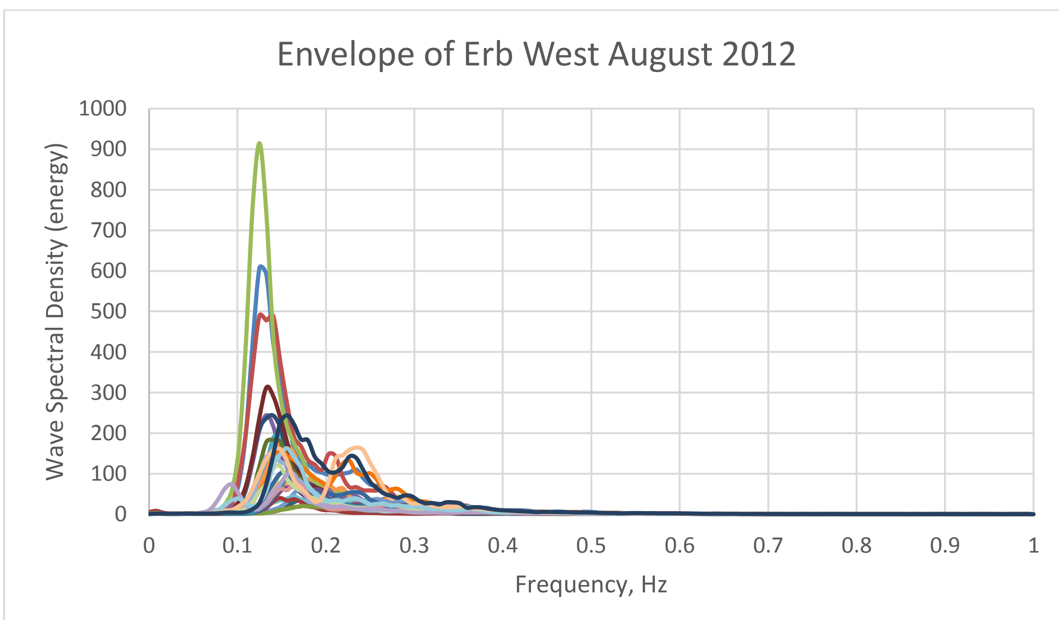


Figure 4.3.5: Wave Envelope Spectrum of Erb West August 2012

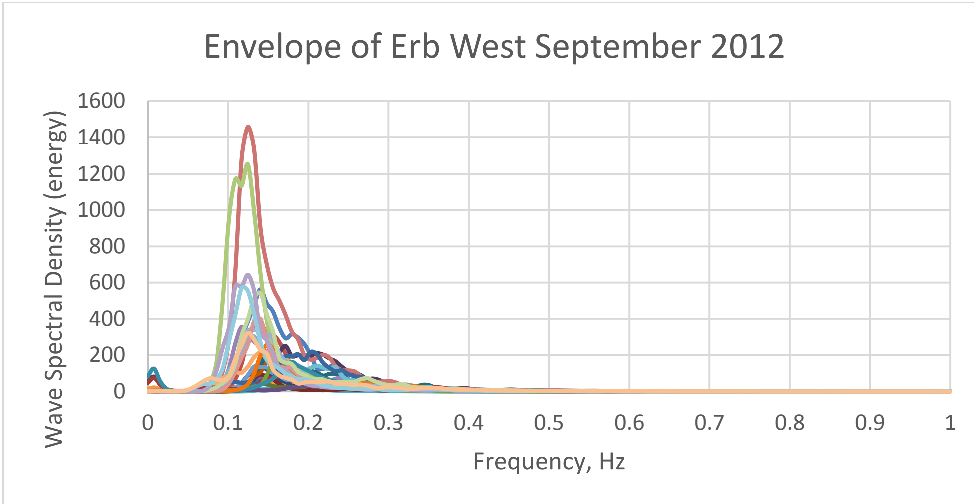


Figure 4.3.6: Wave Envelope Spectrum of Erb West September 2012

From all the spectral plots computed and enveloped for every month, it can be observed that the range of frequency lies within the range of 0.1 to 0.2 Hz. This spectral behavior is consistent throughout the spectral plots computed for all the location in all the months. Through this consistency, it can be said that the Malaysian waves propagates within the region of 0.1Hz to 0.2Hz. Having a huge variation of spectral peak amplitude, the frequency however is consistent, therefore through the identification of spectral peaks for every day of the month the Peak Period, T_p can be determined. Through compilation of the spectral peaks can the peak frequency be captured to compute the peak period for every day and an average of it. A summary on all the collected Peak Periods can be provided below:

Location: Baronia, 2012

month	Avg Peak Period(s)	S.Deviation
10	7.023	1.86
11	7.014	1.016
12	7.332	1.120

Location: Erb West, 2012

month	Avg. Peak Period(s)	S.Deviation
6	6.413	0.6345
7	6.127	0.9364
8	6.360	0.7252
9	6.721	0.8509

The average of all the peak period within a month is tabulated with their respective standard deviation of the peak period throughout the month. As above, in averaging the average of the peak periods for all the months, the Peak Period computed is 6.71 seconds, about 7 seconds. Whereby independently, Baronia holding a Peak Period of 7.123 seconds and Erb West holding a value of 6.41 seconds.

In doubting the procedure of computation, a short study on the procedure and consistency of the results is done whereby a designed amplitude of sine wave with the introduction of noise is to be analyzed. In defining the designed amplitude and computing the amplitude can a comparison be done with the two whereby the percentage of accuracy on the procedure be tested. A design amplitude from 1 to 10 is plotted to observe the behavior of accuracy if high wave amplitude is involved. The tabulation on designed and computed amplitude of wave is as follows:

designed	computed	%tage accuracy
1	0.9488	5.12
2	1.8976	5.12
3	2.8464	5.12
4	3.7952	5.12
5	4.744	5.12
6	5.6928	5.12
7	6.6417	5.118
8	7.5905	5.11875
9	8.5393	5.118
10	9.4881	5.119

Table 4.4: Accuracy test of Design and Computed Values of Amplitude

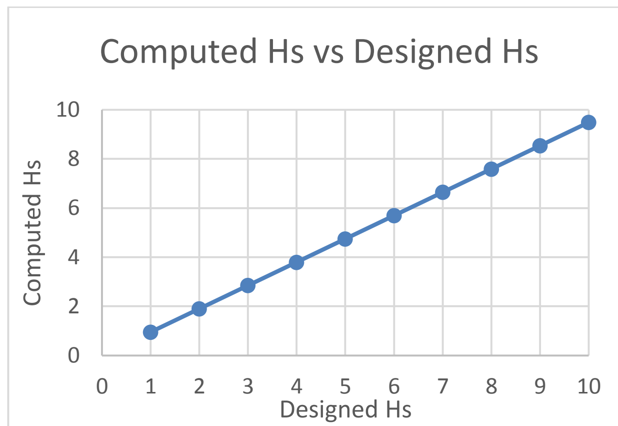


Figure 4.5: Relation of Computed Hs and Designed Hs

Through this short study it can be observed that, the procedure in involving the determination of H_s holds a percentage error of about 5% as shown in the table above. The relation with increase in amplitude proves an insignificant difference in percentage error as the amplitude increase, which for this study proves to be of no harm in the outcome of computing the H_s value. In determining the H_s value in a period every 500 seconds over the course of 24 hours a day an average of the H_s values can be compiled and tabulated as such with the standard deviation of the H_s. The following represents the result:

Location: Baronia, 2012

month	Avg. H_s(m)	S. Deviation
10	7.366	1.253
11	7.438	2.048
12	11.774	3.203

Location: Erb West, 2012

month	Avg. H_s(m)	S. Deviation
6	8.753	3.019
7	8.143	3.459
8	7.541	2.564
9	8.915	3.195

From the compiled H_s values of the average it can be observed that the data in December in Baronia has defects as early detection of error was found in one of the days in the month of December. As highlighted in red, the average H_s values for December is neglected, as such, the average of all the average of H_s values in both the location holds a value of 8.03 meters. Independently, Baronia holds a significant wave height of 7.40m and Erb West holds a value of 8.34m. Through the values obtained for Significant Wave Height, H_s and Peak Period, T_p it can be summarized for the location of Baronia, SKO and Erb West, SBO holds independent values which differs in amplitude less than a meter and differs in period less than 0.5 seconds. A further comparison on the spectrum can be made by plotting the PM and JONSWAP spectrum overlapping the produced spectrum from the results to directly observe the region at which the spectral plot for Malaysian waters lie on. A sample on where does Malaysian basin spectral plot falls on is as follows:

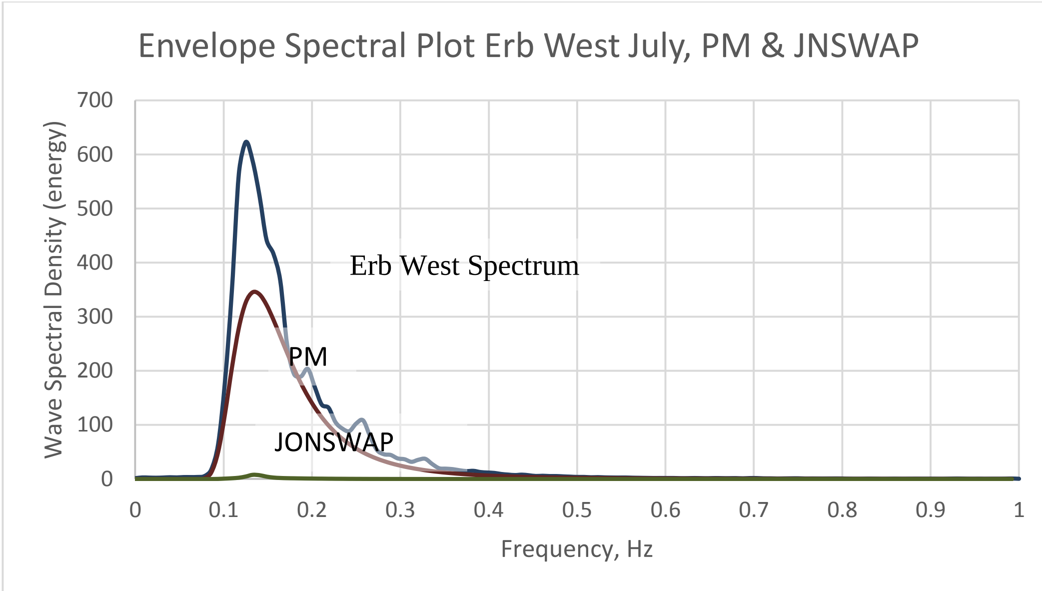


Figure 4.6: Spectral Plot Comparison

In developing the spectral plot for Malaysian basin, it can be seen that the derivation of the other spectrums based on the respective parameters computed shows that Malaysian Spectrum holds a much higher peak of spectral density in magnitude. The PM and JNSWAP spectrum plotted are based on the following spectral formula:

$$S(\omega) = \frac{5H_s^2\omega_0^4}{16\omega^5}\exp\left[-1.25\left(\frac{\omega}{\omega_0}\right)^{-4}\right]$$

PM Spectrum Revised

$$S(\omega) = \alpha g^2\omega^{-5}\exp\left[-1.25\left(\frac{\omega}{\omega_0}\right)^{-4}\right]\gamma^{\exp\left[-\frac{(\omega-\omega_0)^2}{2\tau^2\omega_0^2}\right]}$$

JONSWAP Spectrum

From the spectral plot comparison, a more comprehensive study must be made in order to understand the reason behind the increase in spectral energy of magnitude. From visual observation, the Erb West spectrum exhibit a much similar spectrum to the PM compared to the JONSWAP spectrum. Therefore, a certain gap relation is to be expected from the PM to the Erb West. In relation to the base PM spectrum formulation, the physical parameter can be compared to identify the gap by comparing the H_s and T_p of the spectrums. A sample of relation of these physical parameter can be seen as follows:

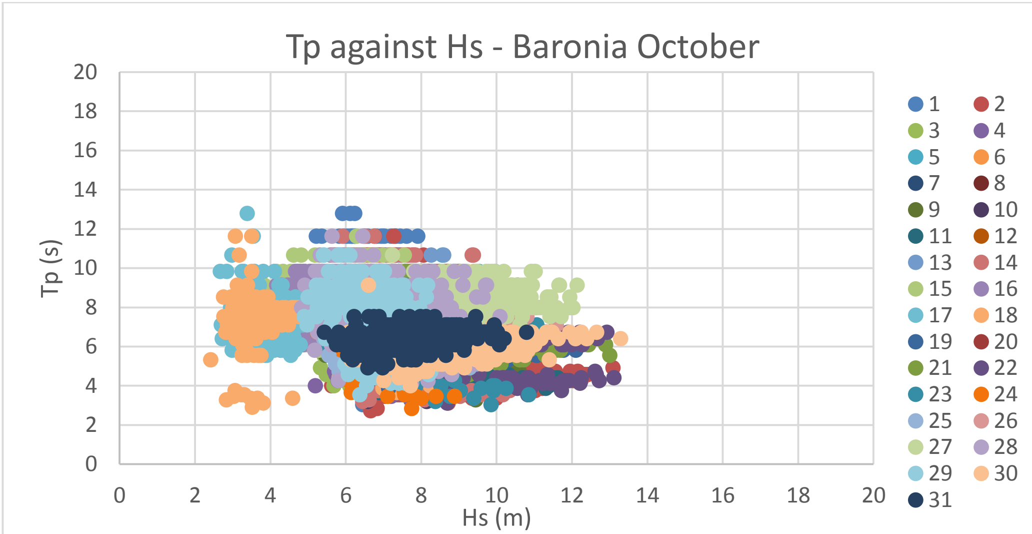


Figure 4.7: Peak Period, Tp against Significant Wave Height, Hs

In order to identify the gap, the existing H_s and T_p relation in the PM formulation can be examined from the alpha parameter in the PM spectrum. This is computed as follows:

$$\alpha = \frac{5\sigma^2\omega_0^4}{g^2} = \frac{5H_s^2 16\pi^4}{16g^2T_p^4} = \frac{5.061H_s^2}{T_p^4}$$

In Charabarti, a common practice of alpha, $\alpha = 0.0081$. By rearranging the alpha, a H_s and T_p relation from the PM spectrum is as follows:

$$\frac{H_s}{T_p^2} = 0.040$$

In order to compare the $\frac{H_s}{T_p^2}$ relation from PM to the Malaysian Water Spectrum, the values for $\frac{H_s}{T_p^2}$ is tabulated and a histogram is plotted as such:

Range	*Frequency*
0.000	585
0.059	387
0.118	3267
0.177	2139
0.236	1672
0.295	1263
0.354	647
0.413	236
0.471	95
0.530	95
0.589	78
0.648	61
0.707	35
0.766	22
0.825	5
0.884	9
0.943	3
1.002	1
More	2

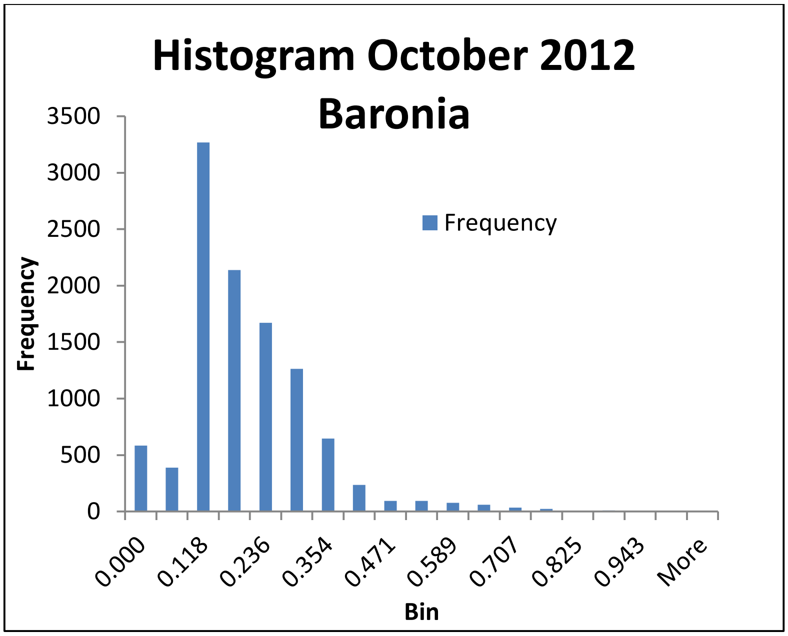
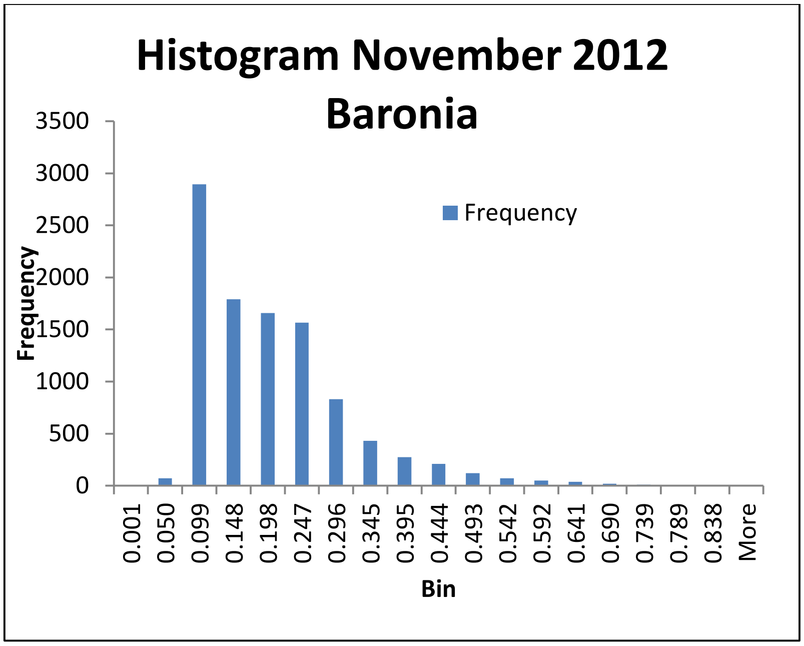
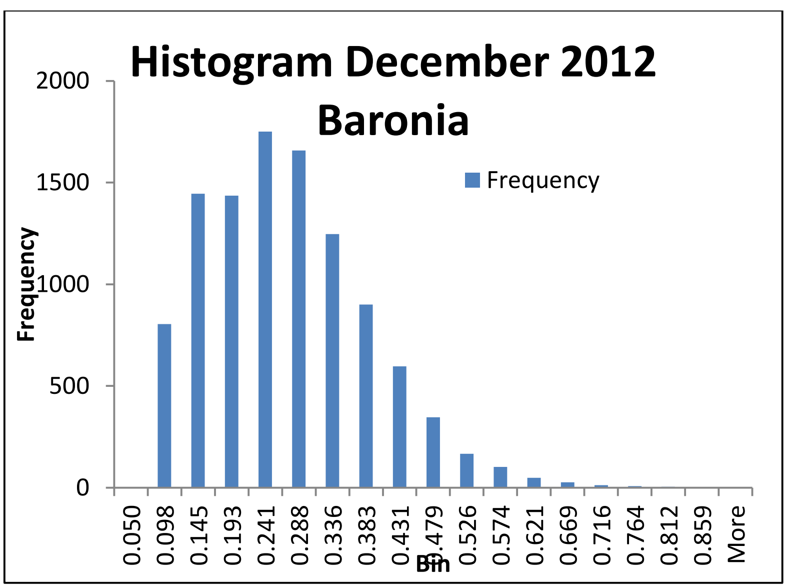


Figure 4.81: Histogram Plot of H_s/T_p^2 and Frequency Range



Bin	*Frequency*
0.001	1
0.050	70
0.099	2894
0.148	1791
0.198	1659
0.247	1565
0.296	831
0.345	430
0.395	275
0.444	211
0.493	120
0.542	72
0.592	50
0.641	38
0.690	20
0.739	11
0.789	6
0.838	2
More	5

Figure 4.82: Histogram Plot of H_s/T_p^2 and Frequency Range



Bin	*Frequency*
0.050	1
0.098	805
0.145	1445
0.193	1436
0.241	1750
0.288	1657
0.336	1247
0.383	901
0.431	596
0.479	347
0.526	167
0.574	102
0.621	49
0.669	27
0.716	12
0.764	8
0.812	4
0.859	3
More	2

Figure 4.83: Histogram Plot of H_s/T_p^2 and Frequency Range

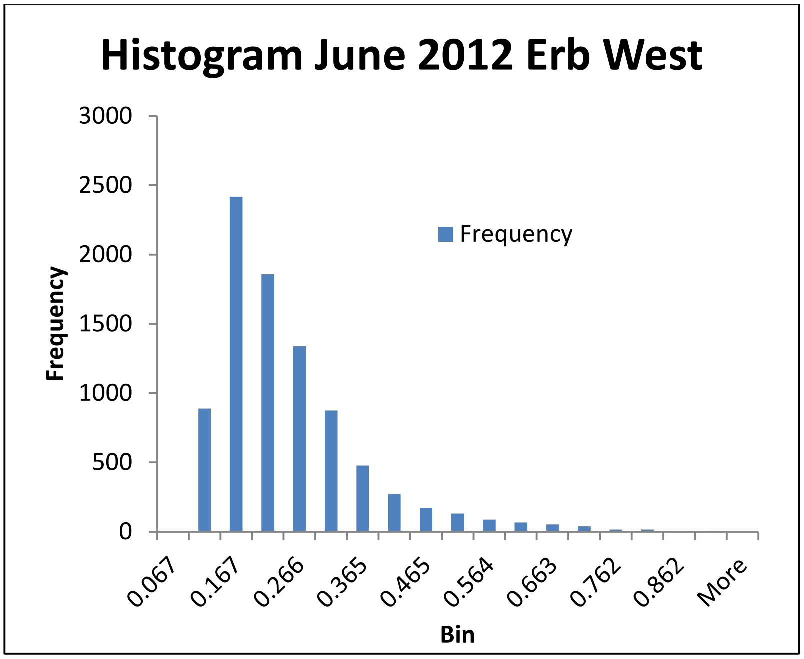


Figure 4.84: Histogram Plot of H_s/T_p^2 and Frequency Range

Bin	*Frequency*
0.067	1
0.117	888
0.167	2416
0.216	1858
0.266	1339
0.316	874
0.365	476
0.415	272
0.465	171
0.514	131
0.564	86
0.613	66
0.663	52
0.713	39
0.762	15
0.812	15
0.862	4
0.911	5
More	3

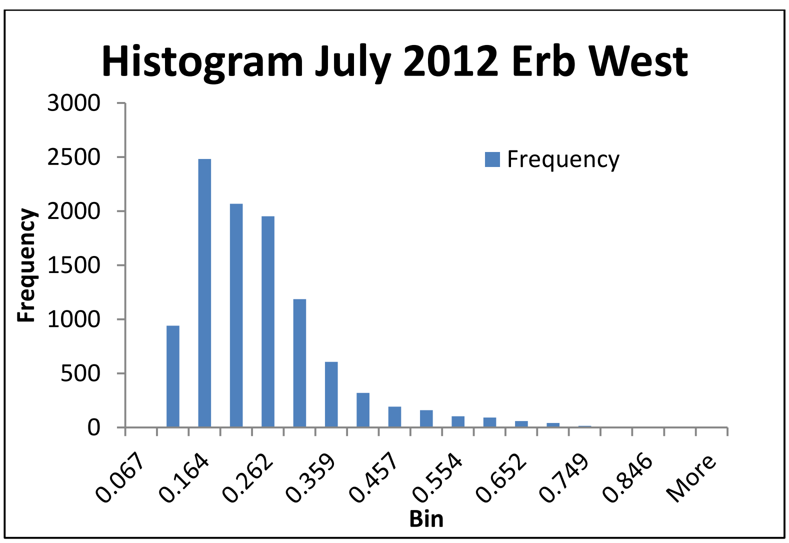


Figure 4.85: Histogram Plot of H_s/T_p^2 and Frequency Range

Bin	*Frequency*
0.067	1
0.116	940
0.164	2483
0.213	2069
0.262	1953
0.311	1187
0.359	608
0.408	320
0.457	193
0.505	161
0.554	103
0.603	93
0.652	59
0.700	42
0.749	16
0.798	5
0.846	0
0.895	1
More	1

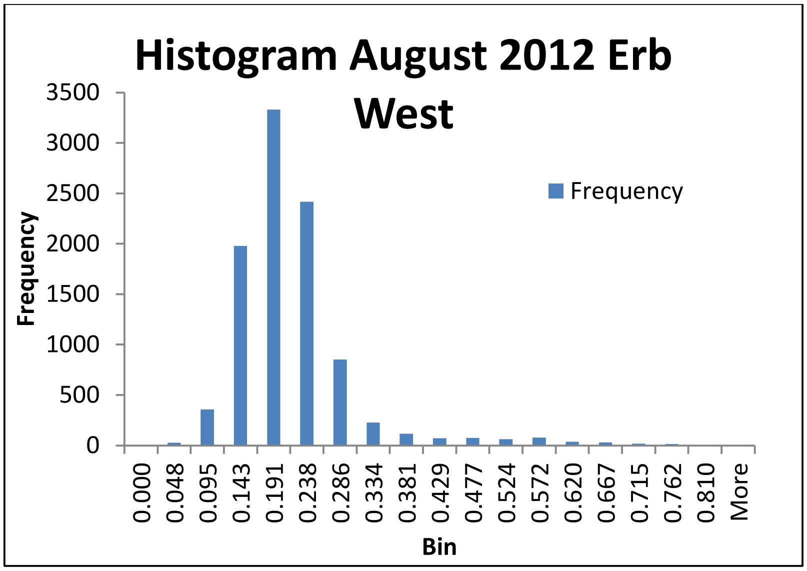


Figure 4.86: Histogram Plot of H_s/T_p^2 and Frequency Range

Bin	*Frequency*
0.000	1
0.048	26
0.095	356
0.143	1978
0.191	3332
0.238	2416
0.286	853
0.334	228
0.381	116
0.429	73
0.477	76
0.524	63
0.572	77
0.620	37
0.667	31
0.715	17
0.762	13
0.810	5
More	5

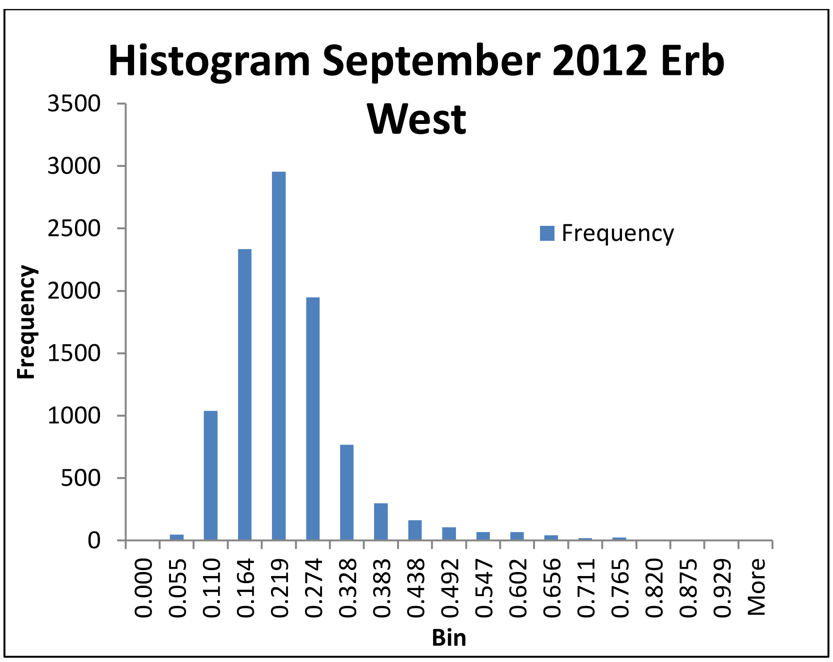


Figure 4.87: Histogram Plot of H_s/T_p^2 and Frequency Range

Bin	*Frequency*
0.000	1
0.055	47
0.110	1038
0.164	2335
0.219	2954
0.274	1948
0.328	767
0.383	299
0.438	162
0.492	105
0.547	67
0.602	67
0.656	42
0.711	18
0.765	24
0.820	7
0.875	3
0.929	2
More	1

Month	10	11	12
H_s/T_p^2	0.118	0.099	0.241
H_s/T_p^2	0.177	0.148	0.288
Average	0.1475	0.1235	0.2645

Table 4.88: Summary of H_s/T_p^2 relation

Baronia, 2012

Month	6	7	8	9
H_s/T_p^2	0.167	0.164	0.191	0.164
H_s/T_p^2	0.216	0.213	0.238	0.219
Average	0.1915	0.1885	0.2145	0.1915

Table 4.89: Summary of H_s/T_p^2 relation

Erb West, 2012

From the tabulated value on the H_s/T_p^2 relation, an average value of 0.1785 for Baronia and 0.1965 for Erb West. From these 2 regional difference, a new alpha, α is to be produced:

$\alpha = \frac{5.061H_s^2}{T_p^4} = 5.061(0.1355)^2 = 0.929$ (Baronia)

$\alpha = \frac{5.061H_s^2}{T_p^4} = 5.061(0.1965)^2 = 0.1954$ (Erb West)

Through this, a factor can be introduced, A in order to fit in the PM spectrum to match the spectrum of Malaysian Waters:

$A_1 = \frac{0.929}{0.0081} = 11.469$ (Baronia)

$A_2 = \frac{0.1954}{0.0081} = 24.123$ (Erb West)

Using the newly found A parameter, a revision to the base alpha formula is to be made:

$$\therefore \alpha = \frac{5\sigma^2\omega_0^4}{Ag^2}$$

In which A is physical parameter which is regional sensitive to SKO or SBO, holding values of $A_1 = 11.469$ and $A_2 = 24.123$ respectively and not a statistical factor.

In understanding this, the nature of the A parameter is to act as an amplification factor to the alpha parameter in the PM spectrum which is tabulated based on recording wave height of Malaysian waters. This finding however was not expected due to an understanding that Malaysian wave spectrum must be less in magnitude compared to that of the PM and JNSWAP spectrum as stated in previous chapters. Which brings to the possibility of error in interpreting the raw wave data.

CHAPTER 5: CONCLUSION & RECOMMENDATIONS

From the results and discussion gathered, the spectral plot for Malaysian water basins is developed and plotted with comparison to other available spectrums. In the process, the significant wave height and peak period of the regions studied in Malaysian basins is obtained, whereby a regional difference was found from the location studied at SKO and SBO respectively to the parameters studied, H_s and T_p . Where H_s at Baronia, SKO holds an amplitude of 7.41m and Erb West, SBO holds a value of 8.36m. The T_p however in contrast, Baronia holding a peak period much higher, 7.19s and Erb West having 6.77s. In a much comprehensive and statistical approach, an amplification factor to the alpha variable in the PM Spectrum is discovered introducing a new parameter termed A, which is regional sensitive to SKO and SBO holding values of 11.469 and 24.123 respectively. This however needs to be further studied as the representation of spectral plots of Malaysian waters was not expected as such. It is recommended that a much more comprehensive Quality Assurance (QA) and Quality Checking (QC) on the available raw wave data be examined as it may be the cause of spectral behavior.

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